9950-1139
DOE/JPL-956334-85/01

DRL No. 188
DRD No. SE-2

JPL Contract No. 956334
FR-60038

A Final Report for:

BLOCK V DOCUMENTATION AND SOLAR MODULES

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA 91103

spire

FR-60038
DOE/JPL-956334-1
Distribution Category UC-63

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A Final Report for:
BLOCK V DOCUMENTATION AND SOLAR MODULES

February 28, 1985

Submitted to:
JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103

Submitted by:
SPIRE CORPORATION
Patriots Park
Bedford, Massachusetts 01730

ABSTRACT

Design and fabrication of Spire Corporation's Block V photovoltaic flat-plate module is reviewed. These modules exhibited power of about 70 watts under standard test conditions. Results of performance and environmental testing are provided.

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SECTION 1
INTRODUCTION

This is the final design report for JPL Contract 956334, "Block V Documentation and Solar Cell Modules." In this work Spire delivered ten high performance flat-plate modules. This report reviews their design, fabrication and testing.

Figure 1-1 replicates the interface control drawing, which indicates the manner in which a 5 kW array is mounted on a residential structure. In Figure 1-2, we show the interface control drawing which illustrates the module construction. These drawings serve to acquaint the reader with the general module design. In Section 2 of this report, we provide additional data on the module design and fabrication.

The Spire Block V modules were formed from cells having an average efficiency of 13%. Module efficiency at 25°C was 10%. Further information on performance and testing may be found in Sections 3 and 4.

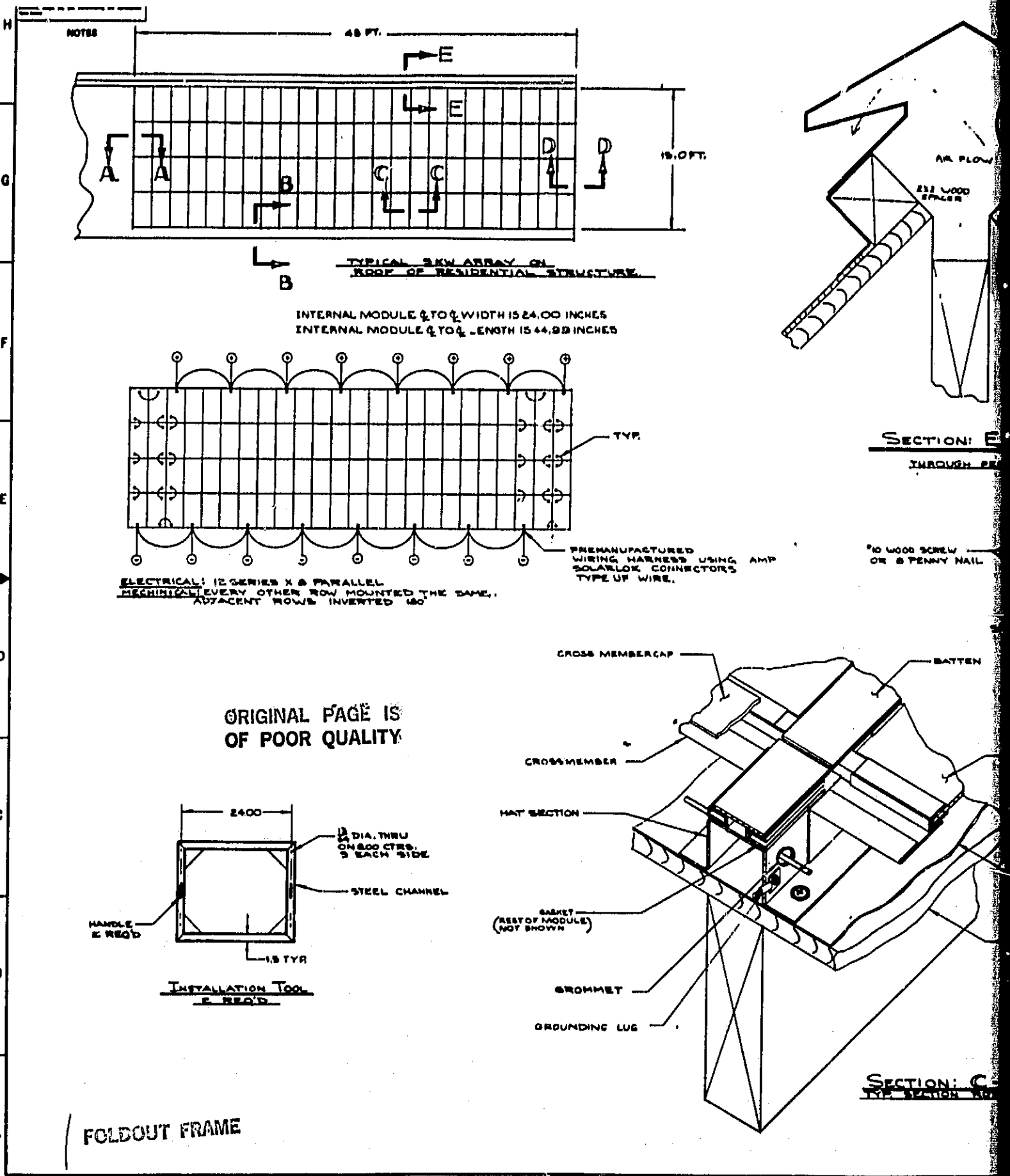

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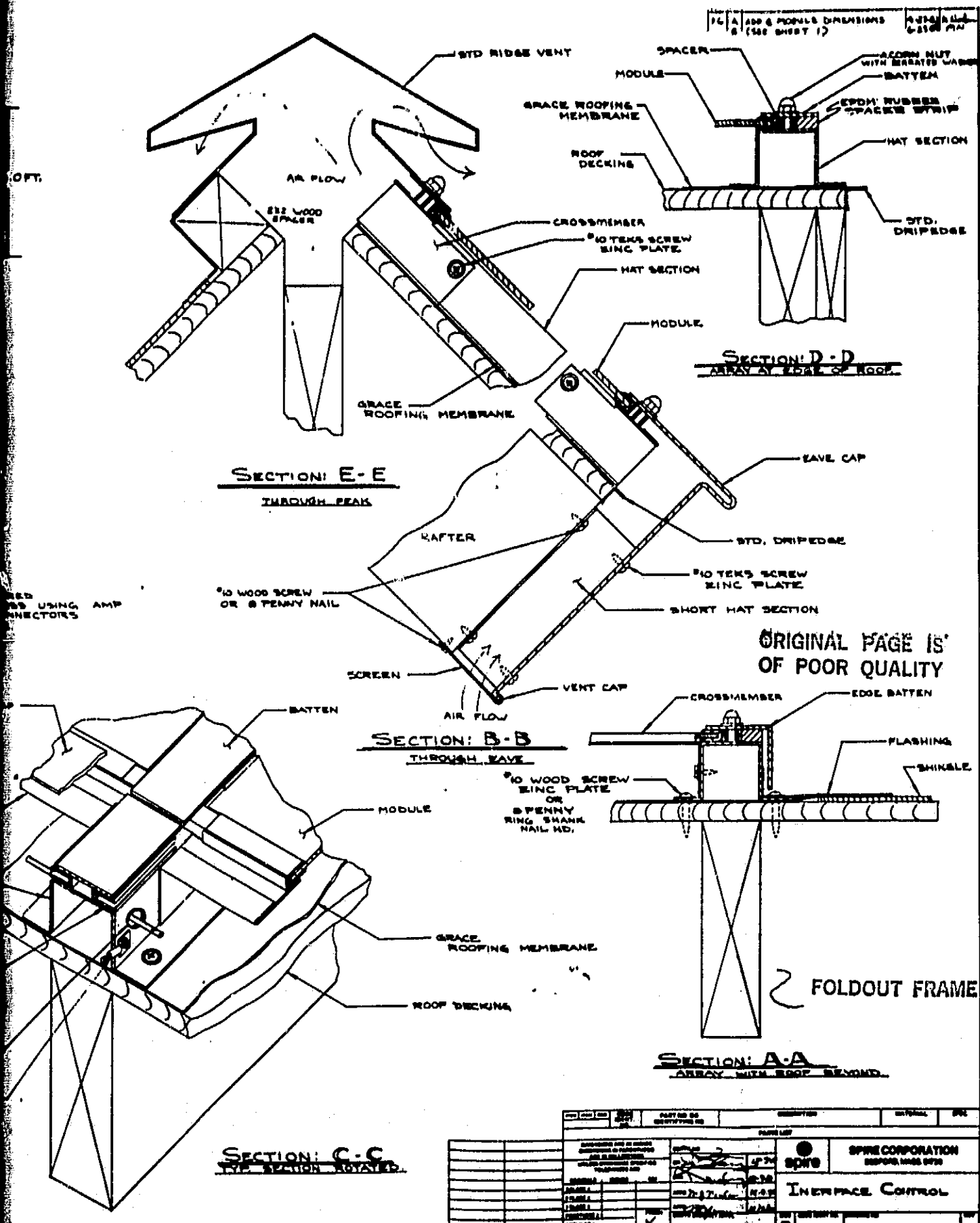
FIGURE 1-1. INTERFACE CONTROL DRAWING ILLUSTRATING ROOFTOP MOUNTING


STD RIDGE VENT
AIR FLOW
2X2 WOOD SPACER
CROSSMEMBER
#10 TEKS SCREW ZINC PLATE
HAT SECTION
MODULE
GRACE ROOFING MEMBRANE
SECTION: E-E
THROUGH PEAK
SPACER
ACORN NUT WITH SERRATED WASHER
BATTEN
EPDM RUBBER SPACER STRIP
MODULE
GRACE ROOFING MEMBRANE
ROOF DECKING
HAT SECTION
STD. DRIPEDGE
SECTION: D-D
ARRAY AT EDGE OF ROOF
EAVE CAP
RAFTER
STD. DRIPEDGE
#10 WOOD SCREW OR 8 PENNY NAIL
#10 TEKS SCREW ZINC PLATE
SHORT HAT SECTION
SCREEN
VENT CAP
AIR FLOW
SECTION: B-B
THROUGH EAVE
BATTEN
MODULE
GRACE ROOFING MEMBRANE
ROOF DECKING
SECTION: C-C
TYP. SECTION ROTATED
CROSSMEMBER
EDGE BATTEN
FLASHING
SHINGLE
#10 WOOD SCREW ZINC PLATE OR 8 PENNY RING SHANK NAIL HD.
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SECTION: A-A
ARRAY WITH ROOF BEYOND
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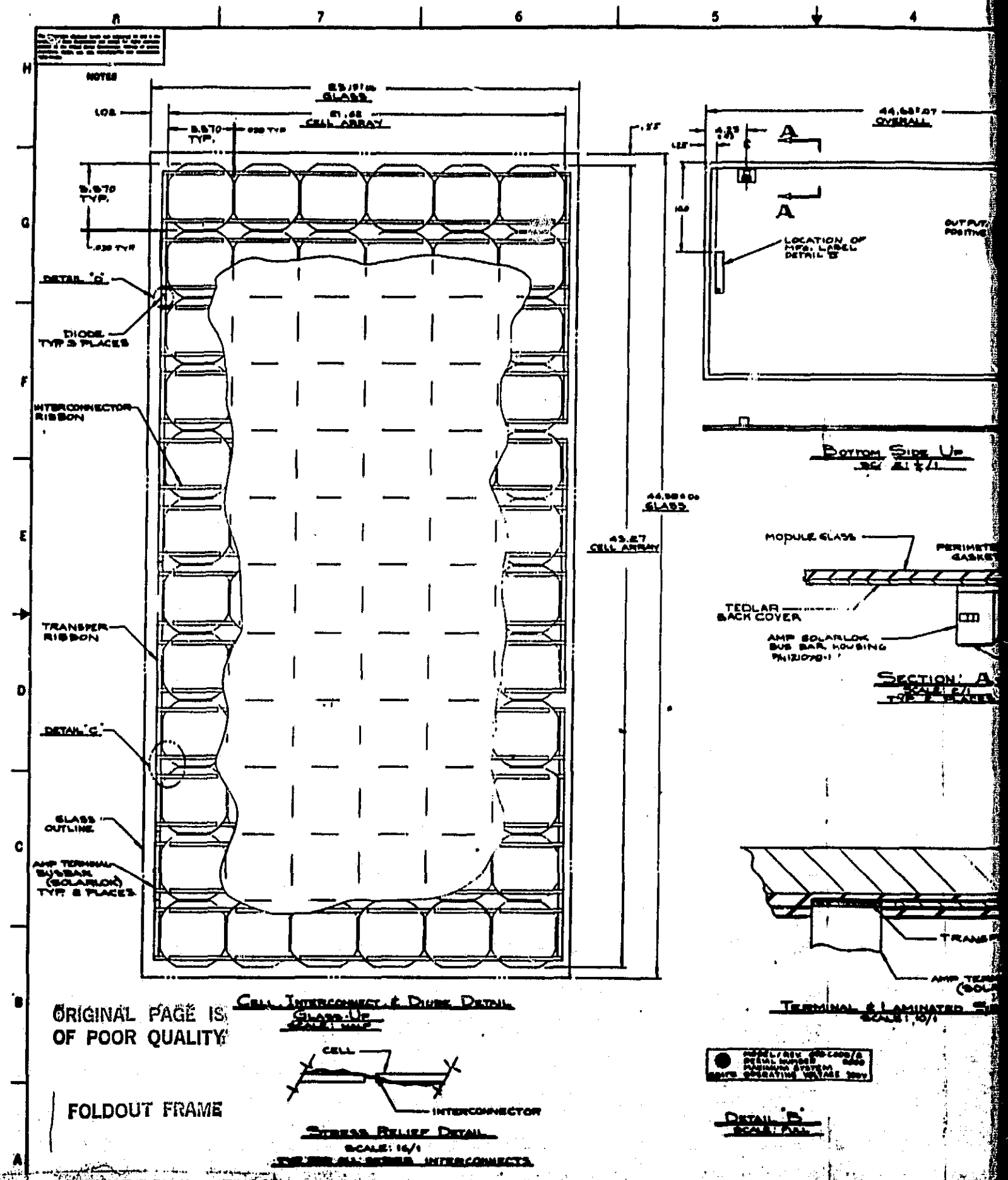
SPIRE CORPORATION
INTERFACE CONTROL
E 4D656 058-0147 B



Cell Interconnect & Diode Detail
Glass-Up

Stress Relief Detail

Bottom Side Up

Section 'A'

Terminal & Laminated

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FIGURE 1-2. INTERFACE CONTROL DRAWING ILLUSTRATING ESSENTIALS OF THE MODULE DESIGN

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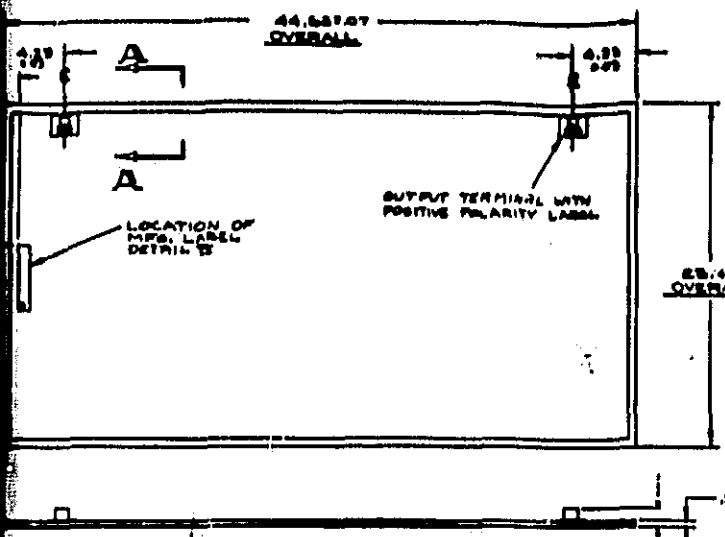

Bottom Side Up
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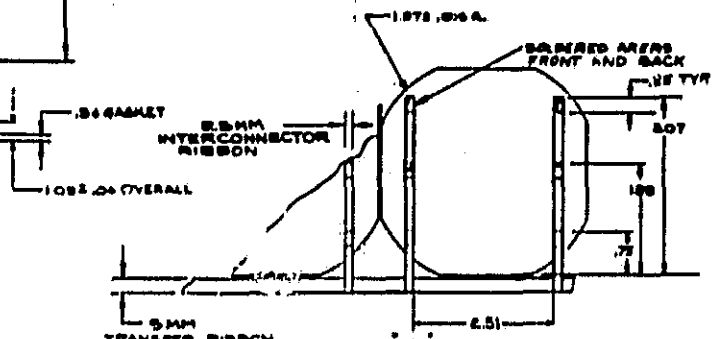
Notes

1. RATIO OF CELL AREA TO MAX MODULE AREA = 75.7%
2. ELECTRICAL PERFORMANCE: P_{max} = 54.4 W; V_{oc} = 19.0 V
3. NOCT = 45°C
4. MAX. WEIGHT = 16 lbs.
5. SHADOW ANGLE = 45° EXCEPT AT CONNECTOR END



Detail 'C'
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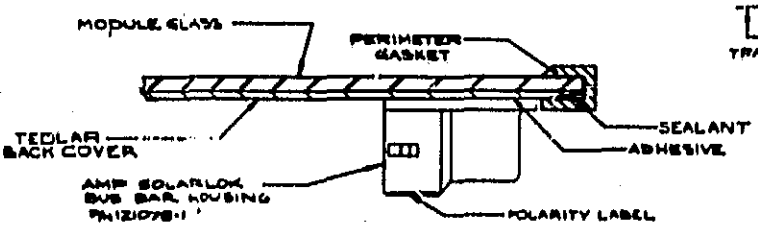
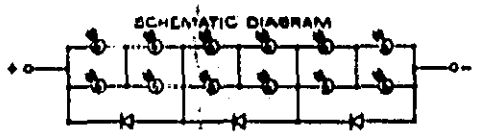
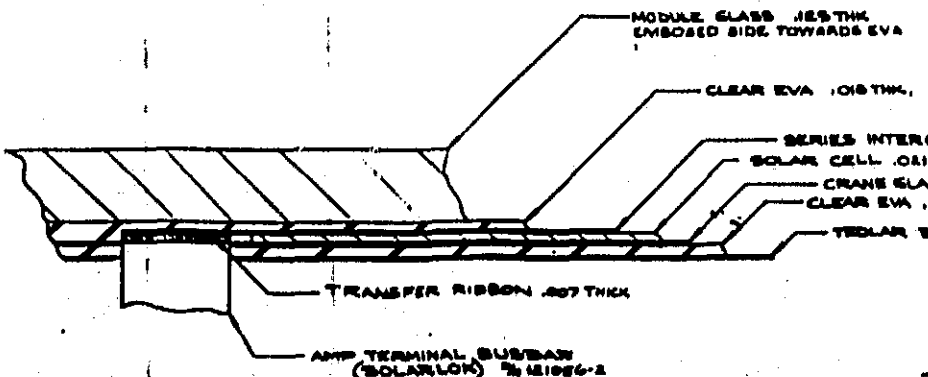


Section A-A
SCALE: Full
TYP 2 PLACES



2 PARALLEL BY 36 SERIES CELL NETWORK, CROSSTIED AT EVERY 6TH. (NUMBER IN CIRCLE INDICATES QUANTITY OF SERIES CELLS)



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Terminal & Laminate Section
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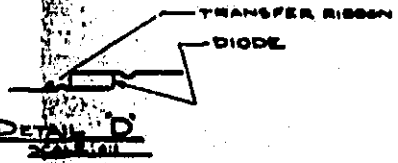

Detail 'D'
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Detail 'B'
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Spire Corporation

Interface Control

E 40686 059-0147 B

A

1-3

SECTION 2
MODULE DESIGN

This section reviews in detail the module design and construction. Included is a discussion of the solar cell and encapsulation system employed.

2.1 MODULE DIMENSIONS

The overall dimensions of the Spire Block V module are 23.44 ± .07 inches by 44.63 ± .07 inches, as shown by the panel assembly drawing in Figure 2-1. The design minimizes edge shadowing for angles of up to 45°. Solar cell packing factor for this design is 75.7%. It can be seen from Figure 2-1 that the module consists of 72 silicon solar cells. Maximum weight of the module is 16 lbs.

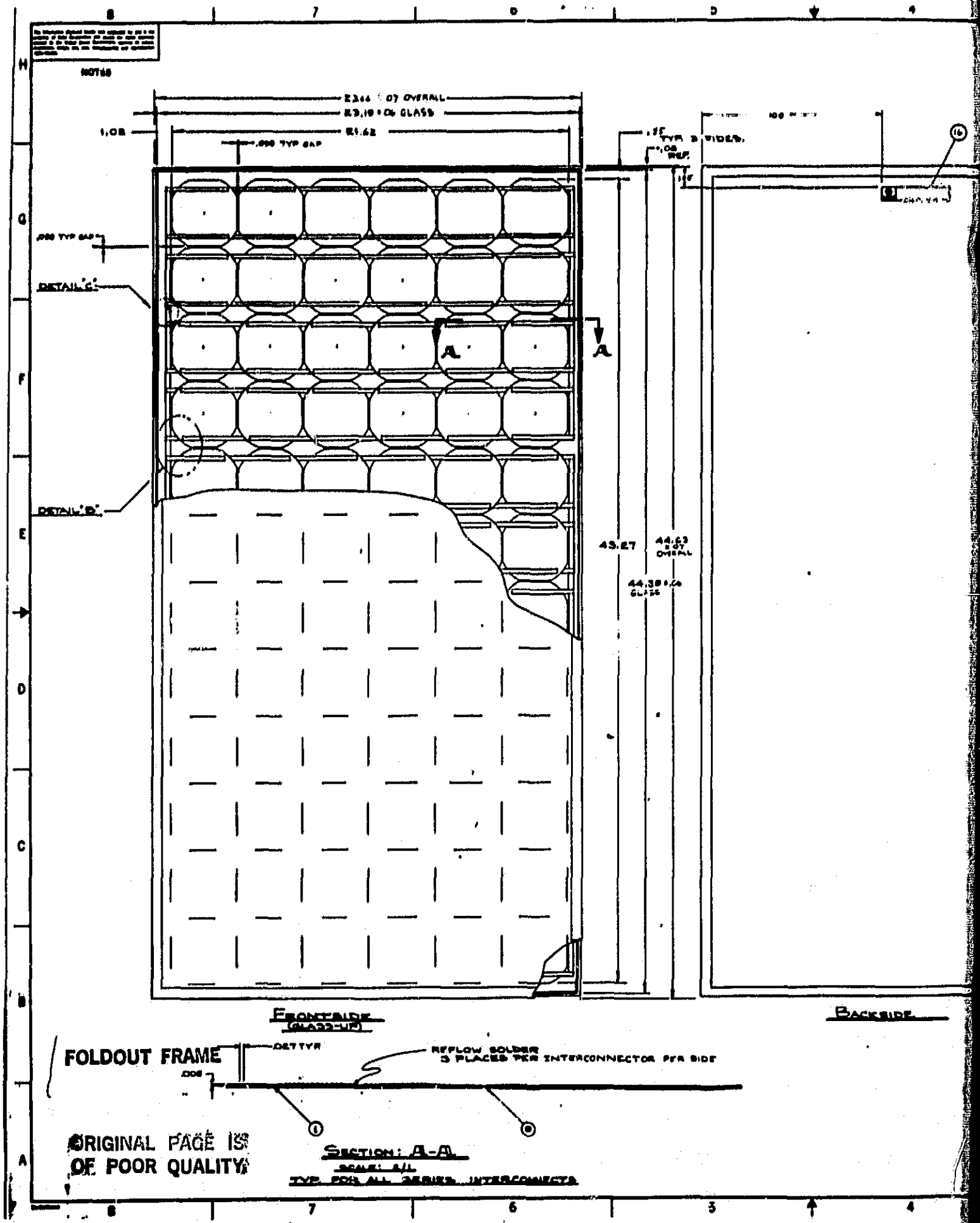
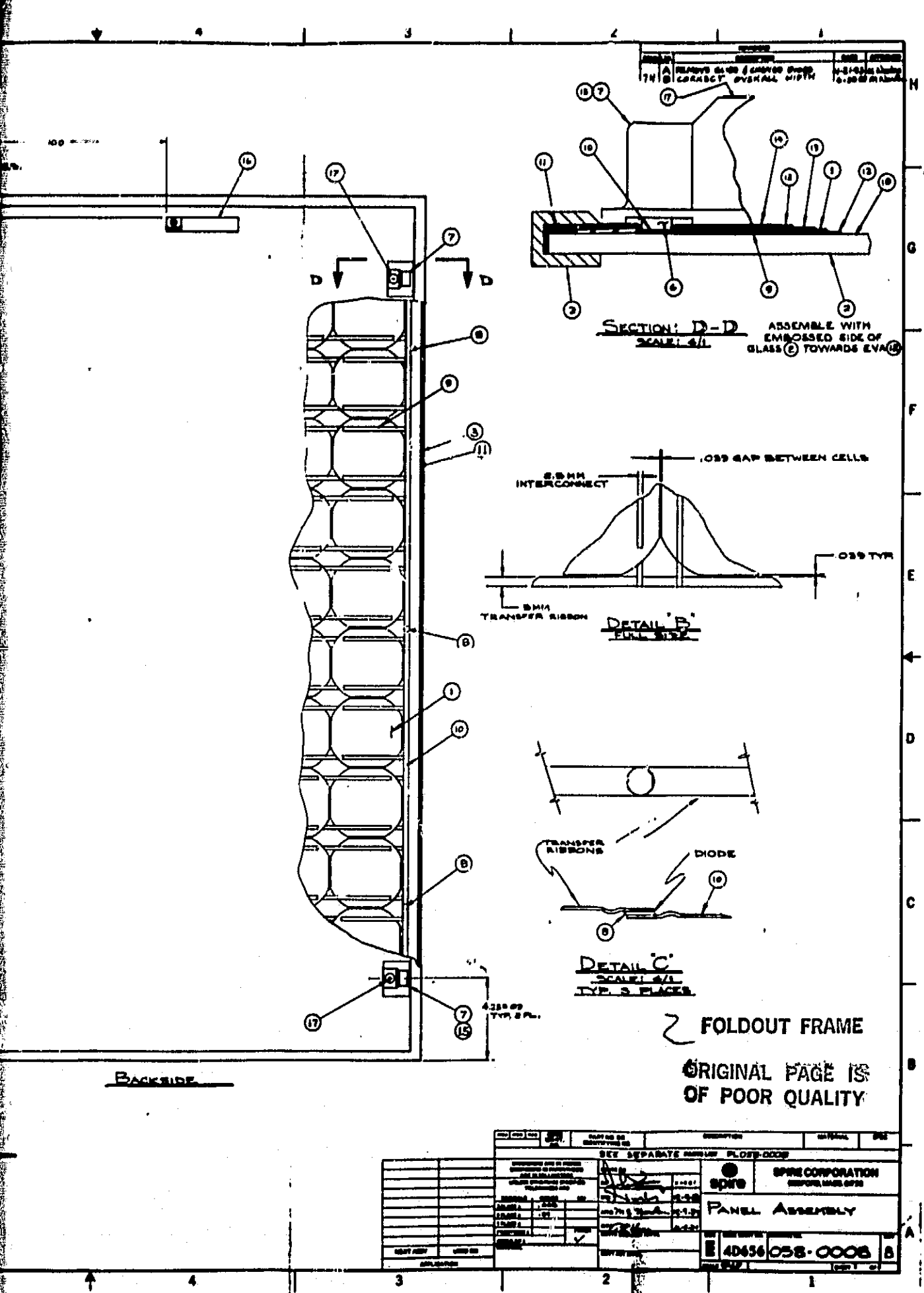


FIGURE 2-1. PANEL ASSEMBLY DRAWING


SECTION: D-D
SCALE: 4/1
ASSEMBLE WITH EMBOSSED SIDE OF GLASS (2) TOWARDS EVA (18)
.039 GAP BETWEEN CELLS
.039 TYP
TRANSFER RIBBON
DETAIL 'B'
FULL SIZE
TRANSFER RIBBONS
DIODE
DETAIL 'C'
SCALE: 4/1
TYP. 3 PLACES
BACKSIDE
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SEE SEPARATE DRAWING FOR PLOTS-0008
SPIRE CORPORATION
PANEL ASSEMBLY
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2.2 ENCAPSULATION AND EDGE SEALING SYSTEMS

The encapsulation system is based on a glass superstrate approach utilizing ethylene vinyl acetate (EVA) adhesive and a laminated Tedlar back cover. Figure 2-2 illustrates a cross-section of the encapsulation system. A fiberglass scrim is employed beneath the back cover for added mechanical strength. All modules were laminated in the SPI-LAMINATOR 240. Figure 2-3 illustrates the edge seal and gasket. No frame was used in this design.

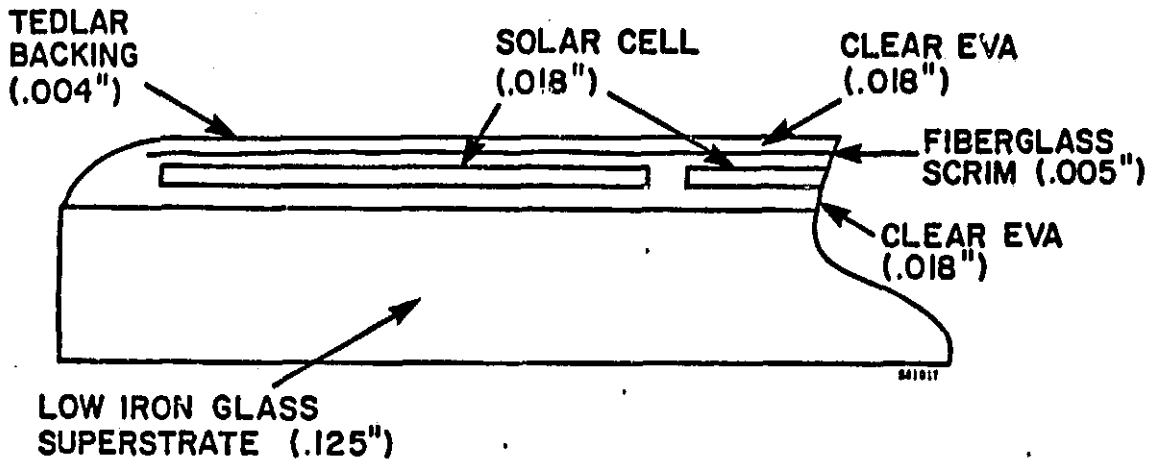

FIGURE 2-2. CROSS SECTION OF THE SOLAR MODULE ENCAPSULATION SYSTEM

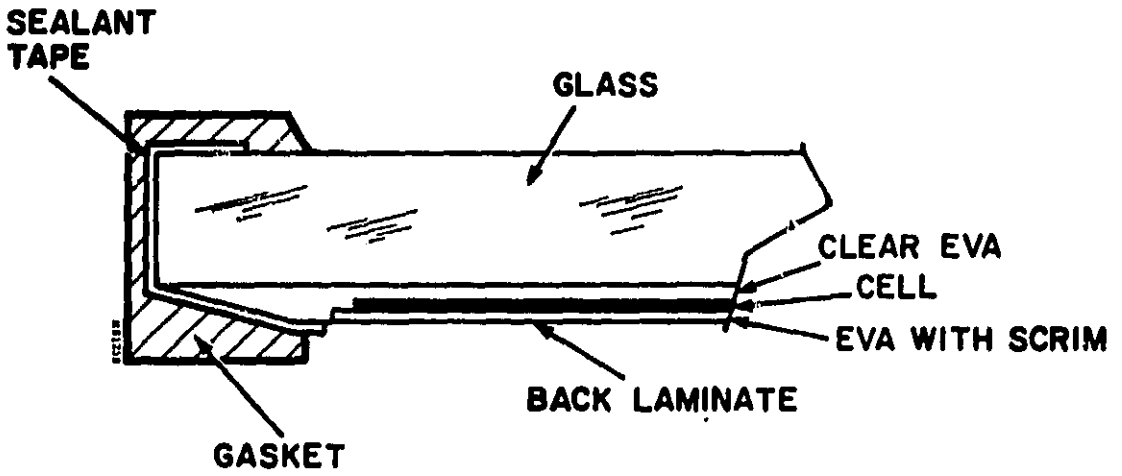

FIGURE 2-3. SOLAR MODULE ENCAPSULATION SYSTEM WITH EDGE SEAL AND GASKET

2.3 ELECTRICAL CONNECTIONS

Electrical connections are made to the module by a prefabricated wire harness. Location of the output terminals is shown in the panel assembly drawing (Figure 2-1). A typical 5.2 kW array is shown in Figure 2-4.

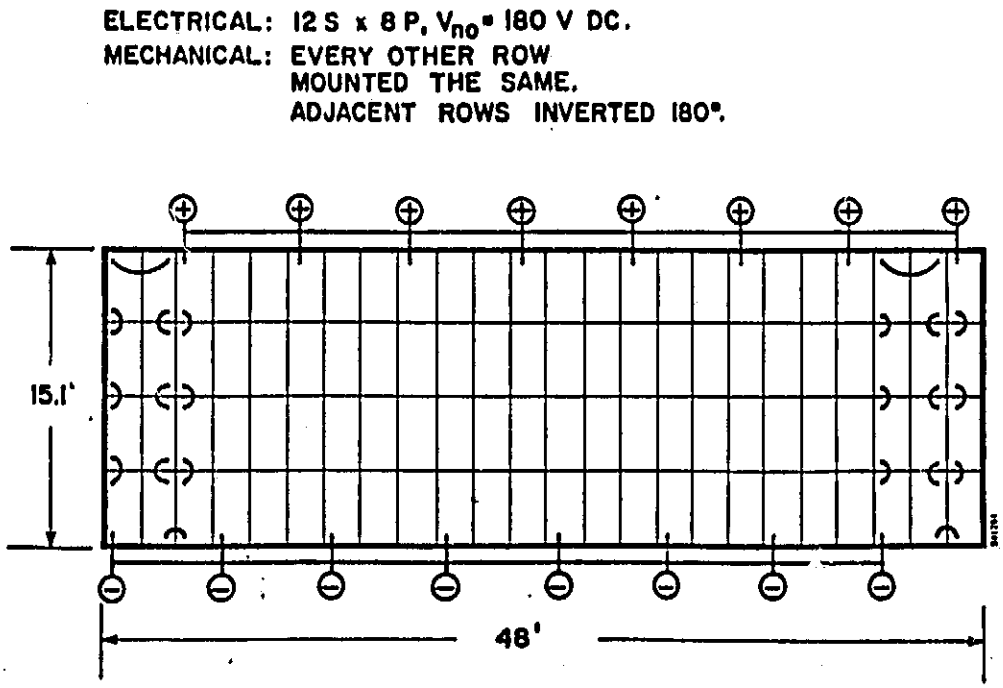

FIGURE 2-4. TYPICAL 5.2 kW ARRAY

2.4 SOLAR CELLS

The solar cells used in the Spire Block V module are made from four inch p-type Czochralski wafers with a nominal resistivity of between 2 and 10 ohm-cm. The junctions are formed by ion implantation of phosphorus and back surface fields are formed by ion implantation of boron, resulting in an n^+pp^+ structure. Nominal thickness of the cells is 20 mils.

Cell metallization comprises lift-off patterned Ti-Pd-Ag. The conductivity of the front grid is increased by electroplating silver onto the contact. All cells have a TiO_2 antireflection coating applied by evaporation.

Figure 2-5 illustrates the grid pattern and overall dimensions of the cell. A parallel busbar interconnect is used to obtain crack tolerance and low contact resistance. Average cell performance was 12.7%.

2.5 MODULE CIRCUIT DIAGRAM

The module circuit diagram is illustrated by a detail in Figure 1-2. It consists of six-cell series strings. The strings are connected in a network of 2 parallel 36 cell strings cross-tied every 6th cell. Three by-pass diodes are connected in series with each other. Each is in parallel with a twelve-cell string, as illustrated in the figure.

2.6 ROOFTOP MOUNTING

Details of mounting were provided in the interface control drawing in Figure 1-1.

NOTES

1. FOR REFERANCE ONLY, CELL IS 0.53 mm (.021 INCH) THICK x 100±0.5 mm (3.94±.031 INCH) DIA.
2. FOR REFERENCE ONLY, CELL FLAT TO FLAT DIMENSION IS 90.7 mm (3.570 Inch)

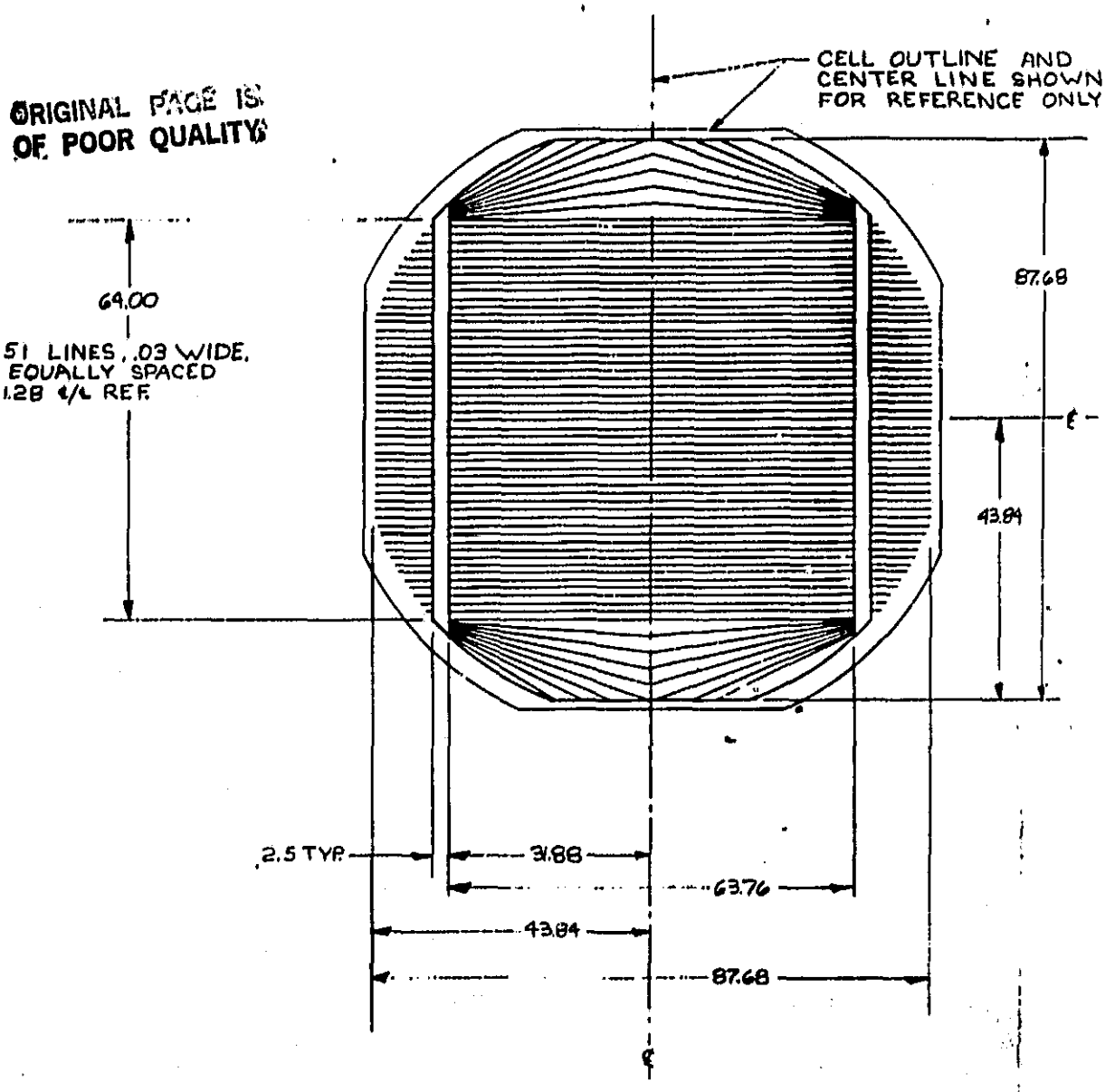

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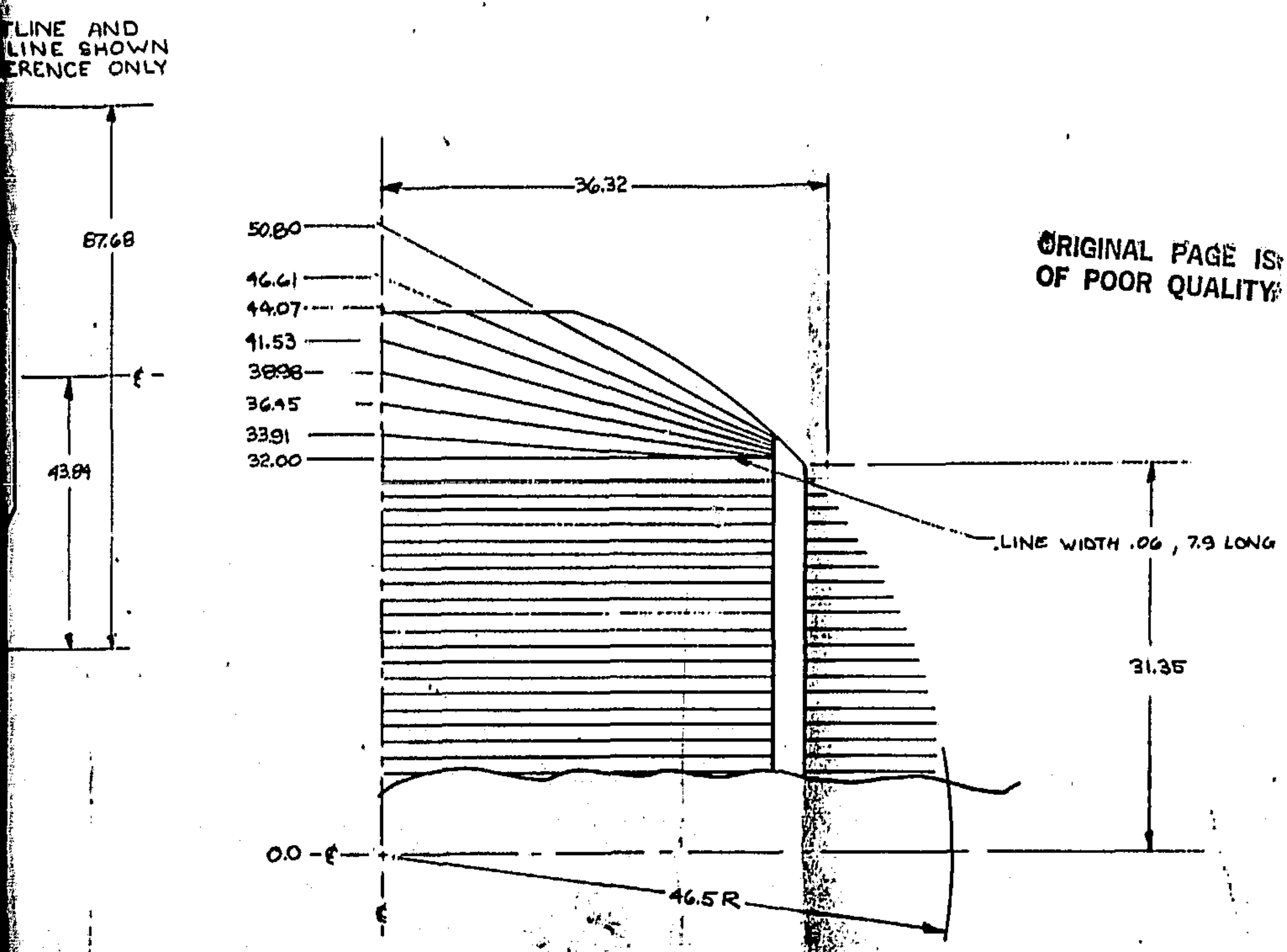
FIGURE 2-5. SOLAR CELL AND PHOTOMASK PATTERN DETAIL

ZONE	LTR	DESCRIPTION	DATE	APPROVED
4C	A	LINE ENDS SHIFTED DOWN .63		
2C	A	LINE SEGMENT MADE DOUBLE WIDE	2-2-82	
3C	A	FOCUS RELOCATED FROM 36.4,32.00 TO 36.3,31.35		
8D	B	ADD NOTE 1	4-20-82	[illegible]
8D	C	ADD NOTE 2	6-22-83	[illegible]



TYP QUADRANT DETAIL - SCALE: 4X

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CODE IDENT NO.	PART NO. OR IDENTIFYING NO.	DESCRIPTION	MATERIAL	SPEC

PARTS LIST

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE: 2 PLACE .01, 3 PLACE .005

DR 1-18-83 · CHK 1-18-83 · APPD 1-13-83

SPIRE CORPORATION
BEDFORD, MASS. 01730

BLOCK V PHOTO MASK-MODIFIED

SIZE	CODE IDENT NO.	DRAWING NO.	REV
D	4D656	058-0159	C

SCALE 2X

SECTION 3
PERFORMANCE

Tables 3-1 and 3-2 list the nominal performance of the Block V module. These were estimated, based on design experience, at the time of the design review.

TABLE 3-1
NOMINAL MODULE PERFORMANCE AT 80 mW/cm^2

Nominal operating cell temperature	49°C
Nominal operating voltage	15 V
Average power	54.4 W
Peak power	78.0 W
Average efficiency	10.1%
Peak efficiency	11.6%
Average operating current	3.63 A
Peak operating current	5.20 A

TABLE 3-2
NOMINAL OPERATING PERFORMANCE AT 100 mW/cm^2

Nominal operating cell temperature	56°C
Nominal operating voltage	15 V
Average power	68 W
Peak power	97.5 W
Average efficiency	10.1%
Peak efficiency	11.6%
Average operating current	4.5 A
Peak operating current	6.5 A

The packing density of the cells in the Block V module is 75.7%. The temperature coefficient used to calculate NOCT performance is -0.335 W/°C. The above values for nominal power were based on experience gained through development of the Block IV solar modules.

SECTION 4
TEST DATA

Test data for the modules delivered in the program are replicated in Table 4-1. Average module efficiency was 10.2% (100 mW/cm^2, 25°C) as measured by JPL.

TABLE 4-1

PERFORMANCE DATA FOR DELIVERED MODULES

Serial Number	Spire Pmax(W)	JPL Pmax(W)
002	74.9	70.8
003	71.3	70.7
004	70.2	70.7
005	72.0	71.3
006	73.4	71.1
007	73.4	71.3
008	70.4	70.1
009	69.6	72.0
010	70.5	72.5
011	70.7	72.5

4.1 Tests and Inspections

Baseline electrical measurements were made and have been reported above. Visual inspection was carried out to obtain a baseline determination of presence or absence of defects. Ground continuity tests were not made, since the module had no external conductive surfaces.

4.2 Environmental Tests

Modules were subjected to the following environmental tests at JPL:

- Thermal cycling (T-50 and T-200)
- Humidity freeze (HF-10)
- Mechanical loading (M-10K)
- Hot Spot (HS-100)

These tests are described in JPL Document 5101-162 (Low-Cost Solar Array Project). Electrical performance test data is summarized in Table 4-2.

TABLE 4-2

SUMMARY OF ELECTRICAL PERFORMANCE
AFTER ENVIRONMENTAL TESTING

Module ID	Test	Output (6)	Delta (%)
SR5H-002	RCVG	70.75	-
	Pre-test	71.20	-
	T-50	70.73	-0.7
	HF-10	70.93	-0.4
	M-10K	69.83	-1.9
SR5H-003	RCVG	70.74	-
	Pre-test	70.52	-
	T-50	71.10	+0.8
	HF-10	70.97	+0.6
	M-10K	69.97	-0.8
	T-200	69.14	-1.4
SR5H-004	RCVG	70.72	-
	Pre-test	70.52	-
	T-50	70.27	-0.4
	HF-10	70.78	+0.4
	M-10K	68.66	-2.6
	Recheck	69.29	-1.7
	T-200	66.87	-5.2
	Recheck	68.36	-3.1
SR5H-005	RCVG	71.25	-
	Pre-test	71.34	-
SR5H-006 (Control Module)	RCVG	71.08	-
		71.34	-
		71.50	+0.2
		71.17	-0.2
		71.10	-0.3
		71.08	-0.4
		70.45	-1.2
		71.00	-0.5
		70.08	-1.7
		70.12	-1.7
		69.39	-2.8
		69.43	-2.7
	Re-check	69.43	-2.7
		70.95	-0.5
		70.43	-0.9
		70.45	-1.2
		70.70	-0.5
		70.86	-0.7

TABLE 4-2 (Continued)

Module ID	Test	Output (6)	Delta (%)
SR5H-007	RCVG	71.34	-
	Pre-test	71.34	-
	T-50	71.21	-0.2
	HF-10	71.37	-
	M-10K	70.25	-1.5
	Pre-HS	70.66	1.0
	HS-100	70.43	-1.3
SR5H-008	RCVG	70.07	-
	Vendor	70.42	+0.5
	Pre-test	70.26	-
	T-50	69.33	-1.3
	Re-check	69.73	-
	HF-10		-
	HF-10	69.44	-1.1
SR5H-009	RCVG	71.98	-
	Vendor	69.63	-3.0
	Pre-test	72.28	-
	T-50	70.55	-1.8
	HF-10		-
	HF-10	69.98	-2.7
SR5H-010	RCVG	72.54	-
	Vendor	70.47	-3.0
	Pre-test	72.28	-
	T-50	71.14	-1.9
	HF-10		-
	HF-10	71.11	-2.3
SR5H-011	RCVG	72.46	-
	Vendor	70.67	-2.5
	Pre-test	72.30	-
	T-50	71.08	-1.9
	HF-10		-
	HF-10	70.87	-2.0

An important problem that was discovered during T-50 temperature cycling tests at JPL was delamination of the back cover. This problem was investigated in detail and found to be related to a need for priming the backs of the solar cells prior to lamination. Subsequent modules fabricated with this problem corrected passed the T-50 test and the humidity-freeze tests. The modules passed the JPL test sequence.

SECTION 5
NEW TECHNOLOGY

No reportable items of new technology have been identified in this contract.